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## Significant problems in FITS limit its use in modern astronomical research

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**Abstract.** The Flexible Image Transport System (FITS) standard has been a great boon to astronomy, allowing observatories, scientists and the public to exchange astronomical information easily. The FITS standard is, however, showing its age. Developed in the late 1970s the FITS authors made a number of implementation choices for the format that, while common at the time, are now seen to limit its utility with modern data. The authors of the FITS standard could not appreciate the challenges which we would be facing today in astronomical computing. Difficulties we now face include, but are not limited to, having to address the need to handle an expanded range of specialized data product types (data models), being more conducive to the networked exchange and storage of data, handling very large datasets and the need to capture significantly more complex metadata and data relationships.

There are members of the community today who find some (or all) of these limitations unworkable, and have decided to move ahead with storing data in other formats. This reaction should be taken as a wakeup call to the FITS community to make changes in the FITS standard, or to see its usage fall. In this paper we detail some selected important problems which exist within the FITS standard today. It is not our intention to prescribe specific remedies to these issues; rather, we hope to call attention of the

FITS and greater astronomical computing communities to these issues in the hopes that it will spur action to address them.

## 1. Introduction

The Flexible Image Transport System standard (FITS; Wells et al. 1981; Hanisch et al. 2001; Pence et al. 2010) has been a fundamental part of astronomical computing for a significant part of the past 4 decades. FITS has provided the central means to store and exchange astronomical data and, because of hard work of the FITS community, it has become a relatively easy exercise for application writers, archivists and end user scientists to interchange data and work productively on many computational astronomy problems.

While there have been significant changes, the FITS standard has evolved very slowly since its creation in the late 1970s. FITS has added new types of metadata conventions such as World Coordinate System (WCS; Greisen & Calabretta 2002; Calabretta & Greisen 2002; Greisen et al. 2006) representation and data serializations such as variable length binary tables (Cotton et al. 1995). Nevertheless, these changes have not been sufficient to match the greater evolution in astronomical research over the same period of time.

Astronomical research now goes beyond the paradigm of the original scientific team consuming only the observational data for which they proposed. Astronomy researchers have shifted towards utilizing the observations of others, accessing data from remote archives over the Internet, and combining these data with the original observations (or theoretical calculations) in order to obtain better and wider ranging scientific results. Many research projects now involve many diverse data sets from a range of sources and instruments in astronomy now produce many orders of magnitude larger datasets than were common at the time FITS was born. Additionally, astronomers have also come to increasingly rely on others to write software to help process and analyze their data. Common libraries, analysis environments, pipeline processed data, applications and services provided by third parties form a crucial foundation for many astronomers' toolboxes.

This evolution in research practice poses many new challenges for the 21<sup>st</sup> century. The large volume of data, the shared software infrastructure, the distributed nature of the data holdings and the increasing complexity of the information we capture mandates that the data format used will enable the machine to do as much as possible handle the interchange, storage and processing of scientific information.

Because FITS has shown difficulties in these areas some members of the community have gravitated away from FITS seeking more capable solutions. Other data formats serving in this role include the Starlink Hierarchical Data System (HDS; Disney & Wallace 1982; Economou et al. 2014) and the adoption of the Hierarchical Data Format version 5 (HDF5) by the Low-Frequency Array for radio astronomy project (LOFAR; Anderson et al. 2011). We predict that the use of FITS will inevitably decline should it not adapt to these new challenges.

In this paper we detail some selected important problems which exist within the FITS standard today. It is not our intention to prescribe specific remedies to these issues; rather, we hope to call attention of the FITS and greater astronomical computing communities to these issues in the hopes that it will spur action to address them.

## 2. Problems – Deficiencies of FITS for Modern Astronomical Computing

There is not enough space in this paper to go into a detailed description of the deficiencies that we see are present in the current incarnation of FITS. Instead we will summarize the issues and present a more detailed examination in a subsequent paper.

### 2.1. Lack of versioning, semantics and encodings

There is no standard way to specify the version of a given FITS file or what extensions it supports. You must read the file and determine dynamically which extensions are present and whether they are understood. The “once FITS, forever FITS” maxim gives you some confidence that you can always read a FITS file but you cannot be sure if there is something that you do not understand. Explicit versioning of FITS files will help but there also needs to be a way to declare that a particular data model is being used from variants such as OIFITS (Thureau et al. 2006), MBFITS (Muders et al. 2006), and FITS-IDI (Greisen 2011), and to validate the contents against a namespaced schema.

The allowed character set in FITS of 7-bit US-ASCII is overly restrictive in a Unicode world. It is unacceptable that FITS authors cannot use special scientific or mathematical symbols (e.g. a degree symbol) or capture non-English text in tables or FITS headers.

### 2.2. Missing data models

FITS can support basic data models such as tables and multi-dimensional images but lacks many higher level data models which enable scientific data description. To start with, there is no standardized way of associating the basic models in a related manner. Determining that a particular image extension contains the variance or mask for another image relies on string parsing and shared convention.

Ironically, for a format designed to handle astronomy data, FITS lacks shared models which describe scientific errors or data quality. Archiving is a primary use case for FITS however it lacks a sufficiently rich model for capturing the history/provenance of the data. The HISTORY keyword provides just a textual representation of provenance which cannot be machine-read, and with a very loose meaning outside particular applications.

Finally, the current FITS WCS data models are complex yet incomplete and inflexible. There needs to be a way to stack mappings in an arbitrary manner to allow for flexible model development (see e.g. Warren-Smith & Berry 1998; Berry & Jenness 2012; Hack et al. 2013).

### 2.3. Inflexibility in representing metadata and data

The 80-character card image drives a number of subsequent limitations which result in poor metadata description (8-character keyword, 68-character limit in keyword values, and cumbersome CONTINUE card constructs). This out-dated restriction also results in the awkward implementation of some conventions, such as ESO HIERARCH (Wicenec et al. 2009), that can not overcome the underlying limitations of representation. Additionally, the lack of namespaces results in uncertainty over metadata meaning with other FITS files. Finally, the 2880 record is a minor but annoying restriction which results in wasteful blocks of whitespace in many FITS files, hampers the use of FITS to capture very small, but richly described data, and impedes the real-time writing of FITS files.

## 2.4. Inadequate support for large, distributed data

Modern data sets can result in files of several terabytes that must be distributed across multiple file systems. The FITS grouping convention tries to provide this facility but is neither robust nor transparent enough. Additionally, streaming indeterminately sized data sets to files must be supported.

## 3. Summary – Significant Problems exist in the FITS standard

The problems which we have described are real and significant. We do not wish to recommend a particular solution here. Action to correct these issues should flow from constructive community discussion, and offered solutions to these problems. Possible solutions may involve moving existing FITS conventions into the core standard, modification of the FITS standard to remove limitations or possibly transferring the FITS data model over into a new serialization, or some selection of these actions.

These technical problems will be solved one way or another. If the community is not willing to do the hard work of hammering out a universal (or widely-adopted) approach, individual projects will continue to make their own ad-hoc solutions. Data formats will become increasingly fragmented and we will no longer enjoy the easy interoperability that FITS has provided for many years.

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